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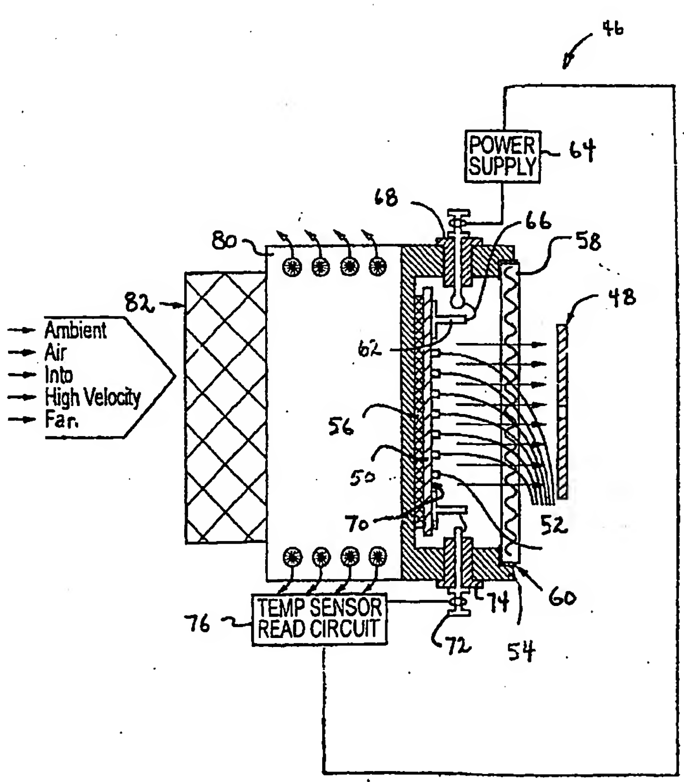
(54) Title: HIGH EFFICIENCY SOLID-STATE LIGHT SOURCE AND METHODS OF USE AND MANUFACTURE



(57) Abstract: A high-intensity light source is formed by a micro array of a semiconductor light source, such as LEDs, laser diodes, or VCSELs placed densely on a substrate to achieve power density output of at least 50 mW/cm2. The semiconductor devices are typically attached by a joining process to electrically conductive patterns on the substrate, and driven by a microprocessor controlled power supply. An optic element may be placed over the micro array to achieve improved directionality, intensity, and/or spectral purity of the output beam. The light module may be used for such processes as, for example fluorescence, inspection, and measurement, photopolymerzation, ionization, sterilization, debris removal, and other photochemical processes.

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High Efficiency Solid-State Light Source and Methods of Use and Manufacture

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This invention claims the benefit of co-pending U.S. Provisional Application No. 60/379,019, entitled "High Efficiency Solid-State Light Source And Use For Molecular Transformations In A Target Material", filed May 8, 2002, the entire disclosure of which is hereby incorporated by reference as if set forth in its entirety for all purposes.

Technical Field

This invention is generally directed to a solid-state light source having an electromagnetic radiation density sufficient to perform a variety of functions in a variety of production and commercial applications.

Background of the Invention

High-pressure arc lamps of various varieties, (for example metal halide, mercury, and halogen) and other high-intensity light sources are used in the majority of commercial and industrial applications involving, for example projection, illumination and displays, inspection, initiation of chemical or biological processes, image reproduction, fluorescence, exposure, sterilization, photopolymer polymerization, irradiation, and cleaning. In each of the applications above, a high irradiation bulb generates a high-intensity broad spectral output of incoherent light that is filtered and spatially modified through the use of complicated optics to allow the emission of a narrow spectral band of light, such as ultraviolet (UV) light with the proper intensity and spatial properties for the desired application. Unfortunately, conventional high-intensity light sources have a variety of disadvantages, as illustrated in the following examples.

UV light is an effective tool in many production applications in many industries. For example, UV light is used for photopolymer polymerization, a process used widely for various processes , such as printing, lithography, coatings, adhesives, processes used in semiconductor and circuit board manufacturing, publishing, and packaging. UV light,

due to its high photon energy, is also useful for molecular excitation, chemical initiation and dissociation processes, including, fluorescence for inspection and measurement tasks, cleaning processes, and sterilization, and medical, chemical, and biological initiation processes, and used in a variety of industries, such as electronics, medicine, and chemical industries. The efficiency and duration of conventional light sources for these applications is extremely low. For instance, 8000W ultraviolet lamp sources (after filtering) are used in exposure of polymer resists, but they provide only 70W of power in the spectral range required by the process. Therefore, more efficient light sources are needed.

Arrays of semiconductor light sources such as LEDs and laser diodes are more efficient than high-pressure light sources and offer advantages over lamps and most other high-intensity light sources. For example such arrays of semiconductor light sources are four to five times more efficient than that of high-intensity light sources. Other advantages of semiconductor light source arrays are that they produce a far greater level of spectral purity than high-intensity light sources, they are more safe than high-intensity light sources since voltages and currents associated with such diodes are lower than those associated with high-intensity light sources, and they provide increased power densities due to smaller packaging requirements. Furthermore, semiconductor light source arrays emit lower levels of electromagnetic interference, are significantly more reliable, and have more stable outputs over time, requiring less maintenance, intervention, and replacement than with high-intensity light sources. Arrays of semiconductor light sources can be configured and controlled to allow individual addressability, produce a variety of wavelengths and intensities, and allow for rapid starting and control from pulsing to continuous operation.

Unfortunately, none of the prior art discloses a semiconductor light source that can be adapted for a variety of applications and/or provide high power densities required by a variety of applications.

Summary of the Invention

The present invention overcomes the problems in the prior art by providing a solid-state light source that can be adapted for a variety of applications and/or having relatively high power density output. For example, the present invention may be used in

material transformation, projection, and illumination applications. Certain advantages of the present invention are achieved by a unique array of solid-state light emitters that are arranged in a dense configuration capable of producing high-intensity power output that prior to this invention required inefficient high-intensity lamps and/or expensive and complex laser or solid-state devices.

The device of this invention is capable of producing power densities greater than about 50 mW/cm^2 for any application requiring such power density. The device of this invention may be used to produce power densities within the range of between about 50 mW/cm^2 and 6,000 mW/cm^2. The device may be configured differently for a variety of applications, each of which may have different requirements, such as optical power output density, wavelength, optics, drive circuitry, and heat transfer. For example, the device may include a drive circuitry to supply power necessary to achieve the density of power output for a particular application. Additionally, the device may include various optics for applications in which a specific light wavelength is required, such as in fluorescent imaging or backside semiconductor wafer inspection.

In one preferred embodiment, the present invention provides a solid-state light module having a thermally conductive substrate with multiple chips of LEDs mounted in a spatially dense arrangement such that illumination is achieved at sufficient intensities to perform physical processes and/or to be utilized in projection and/or illumination applications. The solid-state light source of the present invention can be utilized to perform functions in a variety of applications in such areas of, for example projection, exposure, curing, sterilization, cleaning, and material ablation. The solid-state light source achieves high efficiency, spectral purity, power densities, and spatial characteristics for each of the applications described above, as well as other applications that require efficient light production.

The present invention provides a solid-state light source that is self-contained, thus eliminating the need for intricate optical coupling mechanisms required by many prior art devices. Furthermore, the solid-state light source of the present invention optimizes light output and is advantageous in the design of small, cost effective LED projector systems.

The foregoing embodiments and features are for illustrative purposes and are not intended to be limiting, persons skilled in the art being capable of appreciating other embodiments from the scope and spirit of the foregoing teachings.

Brief Description of the Drawings

Figure 1 shows a schematic view of a basic solid-state light module of the present invention.

Figure 2 shows an exploded view of one embodiment of the solid-state light device.

Figure 3 is a cross-sectional view of another embodiment of the solid-state light device.

Figure 4 is a perspective view of a solid-state light bar.

Figure 5 is a partial cross sectional view of the solid-state light bar of Fig. 4.

Figure 6 is a cross sectional end view of the solid-state light bar of Fig. 4.

Figure 7 is a cross sectional end view of another embodiment of a solid-state light device of the present invention.

Figures 8 and 9 are graphic illustrations of various light waveforms for a variety of applications.

Figure 10 is a schematic view of an embodiment for increasing the intensity of light output from a solid-state light module.

Figure 11 is a schematic view of another embodiment of Fig. 10 utilizing plural optical elements to increase the intensity of light output.

Figure 12 is a schematic of a power supply for driving the embodiment of Fig. 7.

Figures 13a and 13b show an embodiment of the present invention that allows full color display or projection of a color image by having individually addressable red, green, blue, or other color emitters.

Figure 14 shows a method of balancing and controlling the light intensity variations across the LED array.

Figure 15 shows an embodiment of the present invention for projection lithography where an image on a mask is projected onto a photopolymer forming a positive or negative image of the mask in the cured photopolymer.

Figure 16 shows an embodiment of the present invention for cleaning and surface modification where the maximum semiconductor light intensity is further magnified by both optical magnification and pulsing techniques to achieve power densities sufficient for ablation, disassociation, and other effects.

Figure 17 is a schematic of a power control in which individual lines of the array may be controlled.

Figures 18 and 19 are views of a machine vision inspection device for measuring and testing the light output intensity of a solid-state light device of the present invention.

Detailed Description of the Invention

The present invention provides a lighting module that serves as a solid-state light source capable of performing operations in a variety of applications requiring high-density power output. The device of the present invention includes a dense chip-on-board array of solid-state light emitters that produce high-intensity power output and further includes heat transfer; drive circuitry, light intensity, spectral purity, spatial uniformity, and directionality required for a variety of applications. Such applications are typically those requiring a power density output of over about 50 mW/cm^2. Most applications typically require between about 50 mW/cm^2 and about 6,000 mW/cm^2 and the present invention can provide power output in this range. However, it is contemplated that the lighting module of the present invention may be utilized in applications requiring a power density output greater than about 6,000 mW/cm^2. Applications requiring power density output of between about 50 mW/cm^2 and about 6,000 mW/cm^2 include the following:

- projection applications that provide illumination for inspection operations, and for displays and projectors that project and control light;
- imaging applications , such as lithography, printing, film, and image reproductions, and other applications that transfer images; and
- material transformation applications, such as initiating chemical or biological processes, photopolymerization (including curing of coatings, adhesives, inks, and lithographic exposure of photopolymers to create a pattern), cleaning, sterilization, ionization, and ablation (material removal with light).

The lighting module of the present invention includes an array of solid-state light emitters that may be selected from commercially available sources or configured to produce the required wavelength and light intensity for each application of use. As used herein, the phrase "solid-state light emitter" means any device that converts electric energy into electro-magnetic radiation through the recombination of holes and electrons. Examples of solid-state light emitters include semiconductor light emitting diodes (LEDs), semiconductor laser diodes, vertical cavity surface emitting lasers (VCSELs), polymer light emitting diodes, and electro-luminescent devices (i.e., devices that convert electric energy to light by a solid phosphor subjected to an alternating electric field). In the following description, LEDs are used to illustrate solid-state light emitters.

LEDs are arranged in a dense array on a substrate, as discussed below. The density of the chip array or, in other words, the spacing of the chips on the substrate, may vary according to the application of intended use. Each application of intended use may require a different power density output that may be achieved based on the spacing (or density) of the chips on the substrate, depending on the power of chip used. Additionally, each application may require different light wavelengths. Table 1 below shows examples of power density outputs that can be achieved by various chip array densities or spacing using 12 mW and 16 mW chips. For example, an array of 12 mW chips formed on a substrate in a density of 494 chips/cm^2 (22 chips/cm) produces a power density output of 5037 mW/cm^2. This power output density may be required for cleaning applications using light wavelengths of between about 300 nm to about 400 nm. For cleaning applications requiring a higher power density output, an array of about 16 mW chips formed in the same density described above produces a power density output of 6716 mW/cm^2. While individually packaged prior art semiconductors like LEDs, VCSELs, and laser diodes are typically arranged on 4mm or larger center-to-center pitches, this invention unexpectedly achieves significant increases in power density by arranging the devices on center-to-center pitches below about 3mm, and more typically between about 1mm and about 2mm center-to-center pitches. In view of the teachings herein, it should be apparent to one skilled in the art that other power densities, other wavelengths, and other device spacings are possible, limited only by the future availability of devices. As defined herein, a dense array of solid state emitters is a

plurality of solid-state emitters are arranged in an array of about 3 mm or less center-to-center spacing to preferably provide a power density output of at least about 50 mW/cm^2.

Power density (mW/cm^2) as a function of chip spacing and chip power

Micron Pitch	450	650	850	1050	1250	1450	1650	1850	2050	2250	2450	2650
mm Pitch	0.45	0.65	.085	1.05	1.25	1.45	1.65	1.85	2.05	2.25	2.45	2.65
Number of chips per cm	22	15.4	11.8	9.5	8.0	6.9	6.1	5.4	4.9	4.4	4.1	3.8
Number of chips per sqr cm	494	237	138	91	64	48	37	29	24	20	17	14
mW/cm2 using 12mW chips	5037	2414	1412	925	653	485	375	298	243	201	170	145
mW/cm2 using 16mW chips	6716	3219	1882	1234	870	647	500	397	324	269	227	194

Table 1

Figure 1 illustrates the basic construction of the solid-state lighting module 10 of the present invention in which a plurality of solid-state light emitters, such as LED chips 12 are mounted or otherwise disposed in a dense array on a substrate 14. A variety of LED chips are commercially available across a spectral range of visible and invisible light, and a person skilled in the art may select an LED chip depending on the application of intended use. One example of a suitable LED chip for material transformation applications, such as curing, is P/N C395-XB290-E0400-X, manufactured by Cree, Inc., located in Durham, North Carolina, USA. Module 10 is connected to a power source 16 to power LED chips 12 that produce light output of a wavelength and an intensity to perform a desired operation. The spacing or density of LED chips 12 on substrate 14 is determined by the power density output requirements of the desired operation. For example, from Table 1 above it can be seen that to obtain a power density output of about 2412 mW/cm^2, LED chips 12 must be mounted or otherwise disposed on substrate 14 in an array having a density of 237 LED chips/cm^2. For thermal control, substrate 14 is preferably mounted on a heat sink 18. Substrate 14 may be made of a variety of materials, as will be described below. Heat sink may be made of any thermally conductive material, such as aluminum. As described herein, individual LED chips may be surface mounted to or formed on the substrate. However, multiple LED arrays may

be provided as a single integrated circuit die. Larger LED arrays may be assembled by arranging several of the die into a hybrid circuit array.

Figure 2 further illustrates one possible example of a solid-state lighting module 20 capable of producing a power density output that may be used in a material transformation processes. Module 20 includes plural solid-state light emitters, such as LED chips 22 mounted on substrate 24 in a dense array 26 to produce a high-density power output to perform a material transformation process. LED chips that produce a wavelength capable of performing a material transformation process when constructed in an array to produce a power density output of greater than about 50 mW/cm^2 are commercially available. One skilled in the art may select a LED chip depending on its wavelength output for a specific material transformation application. As discussed above, the spacing or density of LED chips 22 depends on the power density output requirement of the material transformation process. Substrate 24 may serve as an electrical insulator and is thermally transmissive and can be made of ceramic material, such as Alumina (Al_2O_3), Aluminum Nitride (AlN); sapphire; Silicon Carbide (SiC); diamond; or Berrylium Oxide (BeO); semiconductor materials, such as GaAs; Si; or laminate-based or other substrates that use thermal vias or metal layers to conduct heat. Hereinafter, a thermally transmissive substrate is one made of any one of these materials. Conductive circuitry patterns 28 are formed on one surface of substrate 24 and are formed of electrically conductive materials, such as copper, palladium, gold, silver, aluminum, or alloys or layers thereof. LED chips 22 are mounted on substrate 24 by solder, conductive adhesives, or other known metal bonding techniques and are electrically connected to circuitry patterns 28 by appropriate conductive leads, such as wires 30. Alternatively, LED chips 22 may be formed directly on substrate 24.

Wires 30 are connected to LED chips 22 and substrate 24 through circuitry patterns 28 by any wire bonding or electrical joining technique, including wire bonding, flip chip, surface mount, or other bonding technique. Circuitry patterns 28 may include connections to thick or thin film passive components 32. Thick film components 32 can be laser trimmed to achieve uniform light intensities across array 26. A power supply 34 is provided and is connected to circuitry patterns 28 to power LED chips 22. Power supply 34 may be connected to or controlled by a computer controller 36 so that LED chips 22 can be turned on, off, or pulsed for variable times or intensities. At least one temperature

sensor 37 may be connected to circuitry patterns 28 or other aspects of the module in any known manner to monitor the temperature of substrate 24 or other aspects of the module. Sensor 37 may be connected through control circuitry to the power supply to prevent the module 20 from overheating. Typically, the temperature threshold is about 80° C. Thus, input from temperature sensors 37 may be used to provide real-time in-situ temperature control. Thermal stability and heat dissipation may be achieved, if desired, by mounting substrate 24 onto a heat sink 38 or otherwise thermally coupling the substrate to the heat sink.

Optical properties of spatial directionality, uniformity and spectral filtering may be achieved, if desired, by an optical element 40, which might include a micro lens array of refractive or diffractive components or other optical redirection technology, as well as spectral filtering. Light output 42 from LED chips 22 can be focused, collimated, and/or made more uniform. Although not required, optical efficiency may be achieved by matching the index of refraction of a gas, liquid, or transparent polymer hermetically sealed in a gap or space 44 created between the substrate 24 and optical component 40. Suitable refracting gases are known to persons skilled in the art and may include helium, nitrogen, argon, or air. The gas may further improve thermal dissipation. Optical efficiency can also be improved by addition of reflective surface coatings on substrate 24 or by the addition of known thin film coatings on optical component 40.

As seen in Fig. 3, one possible example of a solid-state light device 46, capable of curing the coatings on work object 48, such as a CD/DVD storage medium, with a hermetically sealed, air cooled, LED chip array. To perform a curing operation, device 46 may provide a power output density of about 30 to about 200 mW/cm^2 of light of a wavelength of between about 300 nm to about 400 nm. Device 46 includes a substrate 50 made of any material as discussed above but is preferably made of a ceramic or alumina. An array of LED chips 52 is disposed on substrate 50 so as to produce a light pattern slightly larger than work object 48. This larger pattern ensures proper edge cure down the sides of work object 48. Substrate 50 may be enclosed or mounted within a module housing 54. A bonding agent 56 may be used to mount substrate 50 in housing 54. Bonding agent 54 may be selected from known commercially available adhesives. Preferably, bonding agent 54 has heat conductive properties. Housing 54 may be made of a metal that is easy to machine and is an excellent thermal conductor for heat

dissipation. A window 58 of glass or plastic is formed in module housing 54 to allow light produced by LED chips 52 to pass through to work object 48. Window 58 is sealed to module housing 54 by a high light transmission environmental seal 60, which may be any commercially available bonding seal. A terminal 62 is attached to or formed on substrate 50 and is connected to a power supply 64 through a stress relief electric connection 66 mounted in an electrical insulator 68 in module housing 54. An optional temperature sensor 70 is also provided on substrate 50 and is connected through a terminal 72 and insulator 74 to a temperature sensor read circuit 76. Temperature sensor read circuit 76 is connected to power supply 64 to prevent LED chips 52 from overheating. Module housing 54 may be mounted by any connector, such as screws (not shown) on a heat sink 80. Heat sink 80may have a plurality of fins made of any thermally conductive material, such as aluminum. A fan 82 may be connected to heat sink 80 so that fan 82 takes in ambient air and blows it through heat sink 80. Heated air is then transported away from module 46. Many curing applications are performed with light wavelengths of about 395 nm. LED chips 52 preferably produce light output in a range corresponding to that which activates a curing agent in the curing application of intended use. LED chips 52 may be pulsed to increase their output intensity to achieve a power output density of greater than about 400 mW/cm^2 for a particular curing application. However, other curing applications may require other light wavelengths and other power density outputs.

Figures 4-6 show an embodiment that incorporates multiple solid-state light modules into a light bar 84 for in-line material transformation applications, such as high-intensity surface modification such as ink or coating curing or image exposure applications. For example, Low Viscosity Ultraviolet Curing Ink manufactured by International Ink Co. of Gainsville, Georgia, USA, reacts at around 200mW/cm^2 using a wavelength of between about 350 nm to about 400nm. Light bar 84 includes multiple modules arranged in a line or an array and extends along an axis X. Light bar 84 is preferably moved relative to a target or work object along an axis Y allowing light output 88 to perform a process on work object 86. Although not shown, light bar 84 may be mounted on a support for moving light bar 84 over the work object.

Light uniformity is improved by moving light bar 84 relative to work object 86 because the movement spread light output 88 evenly across work object 86 along the Y-

axis. To improve uniformity along the X-axis, light bar 84 may also be moved along the X-axis to spread light output 86 along that axis. Light output 88 may be averaged by moving light bar 84 along both the X and Y axes, such as by vibration. Additionally, a light averaging optical element, such as a diffuser (not shown), may be incorporated in light bar 84. Furthermore, solid-state light modules may be angled so that the witness line of their joining is not evident in work object 86. Light bar 84 may be of various configurations and can be moved by any motive means necessary to achieve the objectives of the process for which it is to be used.

As seen in Figs. 5 and 6, light bar 84 includes one or more solid-state light modules 90 mounted or otherwise disposed thereon. Each module 90 includes a dense array of LED chips 92 mounted or otherwise disposed on a substrate 94. LED chips 92 may be surface mounted and wire bonded to substrate 90 in a high-density array according to the power density output of the operation. Each substrate 94 is preferably a printed circuit board with optimum heat transfer materials, as described above. Substrates 94 may be mounted to a light bar housing 96 through a bonding agent 98, preferably having good thermal conductivity. Modules 90 are mounted in a manner so that light output 88 produced by LED chips 92 is directed toward work object 86 through a window 89. A power supply 100 (Fig. 4) provides power through a first set of cables 102 to power either all modules 90 in light bar 84 or to power each module 90 separately. Each substrate 94 may include a temperature sensor 104. Power supply 100 senses the temperature of each substrate 94 through a second set of cables 106. The first and second cable sets 102 and 106 are shown simplified. Preferably, each module 90 will have its own set of power cables so that each module 90 can be controlled separately. Each temperature sensor 104 is connected to a temperature sensing circuit 108 connected to power supply 100. A power-in bus bar 110 and a power-out bus bar 112 serve as the power input and output connections for light bar 84.

To control the temperature of light bar 84, a fluid circulation channel or conduit 114 may be used to circulate fluid around areas of the light bar requiring cooling. Light bar housing 96 includes upper and lower metal plates 116 and 118, such as aluminum or copper, between which fluid circulation channel or conduit 114 is positioned so that heat is transferred from light bar housing 96 to the fluid which is then carried out of light bar housing 96. Alternatively, light bar housing 96 may be provided with plural channels

120 (Fig. 6) through which coolant is supplied by a first conduit (not shown) so that the coolant is in direct contact with light bar housing 96 and flows out of light bar housing 96 through a second conduit (not shown). This allows for turbulent flow of the coolant, providing greater heat transfer. Power supply 101 (Fig. 4) controls the coolant by sensing the temperature and allowable light output. Light bar 84 is preferably a closed assembly to protect modules 90 from environmental damage, which might result from physical impact or contaminants, either in gas or liquid phase. A rigid cover 122 provides structural strength and holds window 89 which may be coated for improved UV light transmission, if desired. As seen in Fig. 6, at least one optical element 124 may be provided adjacent to or otherwise associated with LED chips 92 to align light output 88 to the Z axis. Optical element 124 may be single or multiple elements and may be separated for each LED chip 92 or be designed to work for several or many LED chips 92.

Other material transformation processes within the contemplation of the present invention may include resist exposure for circuit boards that include at least one material that reacts to light wavelengths between about 350 nm to about 425 nm, with an often suitable wavelength being 365 nm at a power density output of greater than 100 mW/cm^2. The substrate may be ceramic or Aluminum Nitride (AlN) using a fluid cooled heat sink. A collimating optic micro array may be utilized to collimate light output. The LED chips, such as those manufactured by Cree, Inc. as discussed above, may be either be pulsed or driven continuously to obtain a power output density of greater than about 700 mW/cm^2. For some cleaning operations, light wavelengths of between about 300 nm to about 400 nm may be used, as various organic materials can be removed using such a range of wavelengths. For example, fingerprint resides may be removed from a semiconductor wafer using a wavelength of about 365 nm and pulsing the LED chips at less than about 100 nsec pulses to obtain a power output density of greater than about 5,000 mW/cm^2.

Figure 7 shows a solid-state light device 130 wherein optical multiplication of the intensity of the light source is achieved for applications such as semiconductor wafer inspection or fluorescent inspection where a higher intensity of a single wavelength is required. A dense array of LED chips 132 are surface mounted on a substrate 134 having good heat transfer properties as discussed above. LED chips that produce a

wavelength capable of performing an inspection process when constructed in an array providing a power density output of greater than about 50 mW/cm^2 are commercially available. One skilled in the art may select a LED chip depending on its wavelength output for a specific inspection application. Substrate 134 is mounted to a heat sink 136 through a bonding agent 138. Temperature sensors 140 may be provided on substrate 134 and are connected to temperature sensor circuits 142 and are connected to a computer controlled power supply 144 for operation, as discussed above. Power supply 144 is controlled by a computer controller 145 with thermal sensing circuitry and is connected to substrate 134 through power-in bus bar 146 and power-out bus bar 148. Heat sink 136 can be any possible configuration to effectively remove heat and is shown with a plurality of fins 154 to dissipate heat. Either ambient air or air-flow provided by a fan (not shown) flows over heat sink fins 154 to cool device 130. Although an air heat sink is shown, it is contemplated that device 130 could also have a fluid tube to carry coolant into and take heated fluid out of the heat sink 136, as shown and described in Figs 4-6. Additionally, heat sink 136 could also be a heat pipe or thermal electric cooler. Optical elements 150 and 152 may be provided between LED chips 132 and a work object 156 to focus light 158 to obtain the desired intensity required for the application. For example, optical elements 150 and 152 may increase the light intensity up to between 5 and 10 times. Optical elements 150 and 152 may be any known focusing lens or intensifying optic.

Power supply 144, as can other power supplies described above, can provide a variety of power waveforms, as seen in Fig. 8, for different applications. For example, power supply 144 may supply constant voltage continuously at various current levels (amps) as seen in the graphical illustrations labeled 1.1 and 1.2 for applications, such as backside wafer inspection and resist exposure for circuit boards. Power supply 144 can also provide pulsed power waveforms using various time on and off periods represented at C, D, E, and F, and/or current levels (amps) as seen in graphical illustrations labeled 2.1 and 2.2 for applications, such as fluorescent inspection, curing or coating for CD ROMS, and cleaning. As seen in Fig. 9, various ramped current pulses are seen in the graphical illustrations labeled 3.1, 3.2, and 3.3 for applications, such as lithography systems and cleaning. LED chips 132 may be pulsed at various frequencies for pulse times as low as 50 nsecs in order to accomplish a specific function. For material

processing applications where maximum intensity is required, solid-state light devices like LEDs can be super pulsed, for example at currents 3 to 5 times their nominal current for short periods to achieve a higher intensity. Pulse ramp shapes allow more reliability by not overly stressing the solid-state light devices beyond what the application requires. Additionally, for material transformations where the physical process takes a period of time, the duration of the pulse can be matched to the process requirements.

Figure 10 illustrates another embodiment of a high-intensity light source that utilizes a reflective/transmissive optical element for inspection applications requiring power density output on greater than 50 mW/cm^2. Light from a module160 is condensed with a first optical element 162, such as a fused taper, telescopic lens pair, or other optical elements. Module 160 includes a dense array of LED chips 161 surface mounted on a substrate 163. Light is then directed to a work object 164 through a second optical element 166 such as a reflective surface. For fluorescent inspection, module 160 preferably produces light having a wavelength of between about 300nm to about 400nm. Second optical element 166 is preferably a highly reflective mirror that reflects greater than 95% at the light wavelength of about 380 nm and highly transmissive at the fluorescent wavelengths between 450-600 nm. Fluorescent wavelengths from work object 164 are transmitted through second optical element 166 to a camera 168 that detects the fluorescent wavelengths. The simplified optics and higher density light output of this embodiment enables applications not possible with prior art inspections devices due to their complicated design and limited uniformity and power density. The embodiments of Figs. 10 and 11 provide increased light intensity to perform, for example cleaning, sterilization, and other high power density applications. For example, by feeding 1W/cm^2 coherent power into one or more optical devices 162 to form a 1mm^2 to 4mm^2 beam, power density could be increased 100 times, ignoring optical losses. To further increase power density, diode lasers devices in an array could be used instead.

For backside inspection of silicon wafers or for micro electromechanical systems (MEMs) seal inspections, module 160 preferably includes LED chips or laser diodes outputting light a about 1050 nm to about 2500 nm having a combined output power density greater than 50 mW/cm^2. Second optical element 166 is preferably a 50% beam splitter at the same wavelength as the light output from module 160, which is typically between 1100-1300 nm. This arrangement is effective for work objects 164 that are

transmissive at 1100-1300 nm so that the wavelengths transmitted from work object 164 are propagated through second optical element 166 to camera 168 that is sensitive in the near infrared at the source wavelength.

Light output may be further extended by stacking modules 160 as seen in Fig. 11 in series or optically in parallel. For example, 80% efficiency may be achieved by surface mounting 1,000 1.8 mW LED chips at 1200 nm on substrate 163 in module 162(a); surface mounting 800 similar LED chips of substrate 163 of modules 162(b) and 162(c). This provides a potential of 1.44W with one module, 2.59W with two modules, and 3.7W with three modules. Figure 12 illustrates a power supply capable of achieving the pulsing and control requirements of the present invention. The programmable power supply shown herein is controlled from a general-purpose instrument bus (GPIB) interface circuit board where the output voltage and output current can be remotely programmed and monitored from a computer. The power supply can also be programmed to provide arbitrary output voltage and output current waveforms at various pulse repetition rates and duty cycles sufficient to achieve the functionality detailed in the embodiments.

Figures 13a and 13b show an embodiment of the present invention that allows spectral mixing by having individually addressable light emitters of predetermined colors. For example, the emitters can be red, green, and/or blue. The emitters can be arranged in color triads. In addition to standard LED colors, LED chips may be adapted to produce other colors by using color-specific phosphors or fluorescing coatings or fillers. Examples of such fillers are described in U.S. Patent No. 6,459,919, which is incorporated herein by reference. For example, each LED in earlier described embodiments may be replaced with three LEDs. In other words, one white LED may be replaced with three LEDs of different colors, R,G, B (Red, Green, Blue) with each separate LED having separate power coming in so that the drive circuitry would allow them to be pulsed as separate colors. White-light LEDs using phosphor coatings are commercially available.

Grounds for a triad of LEDs can either be separate or one single common ground. A solid-state light module 170 is partially seen in Fig. 13 in which a substrate 172 includes an array of R, G, B LED chips 174 mounted thereon having a high spatial power density so that the resulting illumination is sufficiently intense and uniform to

achieve the required projection brightness. Projection applications contemplated by this invention typically would require a very dense arrangement of LED chips, such as about 237 LED chips/cm^2. Such high density can be achieved by making substrate 172 a multilayer printed circuit board that brings the R, G, B interconnects together. Substrate 172 may include at least one temperature sensor 176 that operates to control temperature as discussed above. Module 170 is similar to module 20 described in Fig. 2 with the main exception being that the solid-state light emitters are R, G, B emitters. Module 170 is preferably mounted on an air cooled heat sink (not shown here) similar to that described in Fig. 3 and includes drive circuitry that produces light intensity and spatial light distribution required for projection applications, such as desktop projectors. Furthermore, the R, G, B LED chips 174 and/or any optics may be controlled to allow single device control.

Figure 13b shows the addition of an optical element 178 provided adjacent to LED chips 174 to achieve color through intensity. Optical element 178 may include phosphors of different colors. The each phosphor may react to a specific light intensity or a range of light intensities so that different colors may be provided by varying the light intensity of the LED array. Thus, a single wavelength light produced by the LED array may produce multiple wavelengths of light depending on the intensity of LED light output 179 intensity so that two, three, or more different wavelengths or colors can be obtained from optical element 178. If desired, each LED chip 174 may be individually intensity controlled; however, individual control of each LED chip 174 is not required. Light output may be R, G, B, and light conversion may or may not be by phosphor layers on optical element 178.

Figure 14 shows methods of balancing and controlling the light intensity variations across the LED array. This feature may be added (if required) to all embodiments described herein. Light output of LED or series of LEDs are controlled by varying line resistance of DC current flow. Control of current flow will control LED light output intensity. Varying intensity provides the ability to balance light intensity evenly over an LED array. Varying intensity allows control over the LED array light output to achieve non-uniform light intensity. In a first illustrated method, LEDs 180 are arranged in a series with a laser trim resistor 182 anywhere in the series. In a second illustrated method, the circuit current carrying ability inside the LED array is varied.

This may be achieved by varying the size of the wire bonding the LEDs 180 to the substrate. Wire is available in varying diameter (for example 0.001 in., 0.002 in., and 0.003 in. gold wire). Resistance of the power circuit may be controlled by varying the printed circuit board trace width and/or plated thickness. Additionally, different LEDs can have different traces as needed to control current flow. Alternatively, the LEDs can be controlled using a programmable current source implemented as a transistor-based circuit to balance the current among arrays of LEDs connected in series, and/or to arrays of LEDs arranged in rows and columns. The current source may also be implemented as a programmable current output power supply.

Figure 15 shows one possible embodiment of the present invention for projection lithography where a module 190 projects an image on a mask or liquid crystal display 192 onto a photopolymer work object 194 forming a positive or negative image of the mask in the cured photopolymer. Liquid crystal display 192 may be connected to a power source (not shown) in a manner shown and described with reference to Figs. 4-6. Projection lithography requires a very uniform light source. Module 190 includes a substrate 196 with a dense array of LED chips 198 and an air-cooled heat sink 200 as discussed above. LED chips that produce a wavelength capable of performing a projection process at a power density output of greater than 50 mW/cm^2 are commercially available. One skilled in the art may select a LED chip depending on its wavelength output for a specific projection application. A collimation optic element 202 may be provided to collimate light output from the LED array and either a reducing optic 204 or an enlarging optic 206 is provided depending on the size of the image to be projected.

Figure 16 shows one possible embodiment of the present invention for cleaning and surface modification where the maximum semiconductor light intensity is further magnified by both optical magnification and pulsing techniques to achieve power densities sufficient for ablation, material or molecular disassociation, and other effects. A module 208 includes a substrate 210 with a dense array of LED chips 212 having a power supply similar to that discussed with reference to Figs. 4-6. A single or multiple lens 214 is provided to achieve linear magnification of light output 212 from module 208 to perform an operation on a work object 216.

The lighting module of the present invention may be utilized in a variety of applications that require high-intensity ultraviolet light. For example, the lighting module may be used in fluorescence applications for mineral, polymer, and medical inspection and measurement by using a power output density of between about 10 to about 20 mW/cm^2 of light of a wavelength of less than about 400 nm applied for at least a duration of about 40 msec. For water sterilization, a power output density of between about 2 to about 42 mW/cm^2 of light of a wavelength of about 254 nm may be provided and for sterilization of blood or other biological material, a power output density of about 80 mW/cm^2 of light of a wavelength of between about 325 nm to about 390 nm may be provided. In polymer curing of, for example adhesives, paints, inks, seals, conformal coatings, and masks, a power output density of between about 30 to about 300 mW/cm^2 of light of a wavelength of between about 300 nm to about 400 nm. For imaging exposure for, for example circuits and printing, a power output density of between about 25 to about 300 mW/cm^2 of light of wavelengths of about 246 nm, 365 nm, 405 nm, and 436 nm is provided for a duration of between about 6 to about 30 seconds. In stereo lithography applications for rapid prototyping, a power output density of greater than about 10mJ/cm^2 of light of wavelengths between about 325 nm to about 355 nm is provided for a duration of about 20 nsec. For organic cleaning applications for debris removal of, for example epoxy or fingerprints, a power density output of between 60-500 mJ/cm^2 of light of wavelengths of about 172 nm and about 248 nm for a duration of 20 nsec. In photo ablation applications for material removal, a power output density of about 1 E7 W/cm^2 of light of a wavelength less than about 400 nm is utilized for a duration of about 20 nsec. The light might be pulsed by drive circuits and optical elements may provide an improvement of directionality and uniformity, perhaps with gradient index planar lens materials.

In applications in which the module is used for projection the module may be used to drive fluorescing material to generate the required R, G, B output. For example, three phosphors may be used as a target and one or more phosphors may be activated depending on the intensity of the light output. This application may be used to create visual interest or for small televisions. The present invention also contemplates embodiments of the invention for deformable mirror device (DMD) and LCD based

projection devices, which would overcome the problem of light output balancing from R, G, B LEDs.

Additionally, a variety of other applications including water treatments including splitting, disinfecting, ionizing, and reduction of pollutants; polymerization of medical coatings, conductive inks, controlled release drugs, and furniture coating; sterilization of medical devices, blood products, medicines, and airborne particulates; diagnostic and therapeutic uses of light for dental, skin treatment for a variety of diseases, mental disorders, and identifying particular materials through spectrographic or chromatography methods; agricultural uses including stimulating plant growth or preparing plant transitions from artificial to natural sunlight; environmental applications including the degradation of materials to accelerate biodegradation.

In exposure applications, higher coherence, spectral purity, and/or directionality of light could be achieved by including anti-reflective coated side enclosures for each LED or diode to avoid side reflections and interference effect. This will effectively prevent creative and/or destructive interferences from up-close. Alternatively, the modules can be enclosed in a series of reflectors to dramatically increase the distance to the work surface to ensure greater spectral purity. Alternatively, micro lenses could be fabricated on the LED pitch spacing to improve collimation. Such lenses might be, for example gradient index diffractive optics or Fresnel lenses. Furthermore, distributed Bragg Reflectors formed by dielectric coatings could form a resonant cavity, which would improve light directionality. Additionally, a planar collimator, such as an assembly of one or more stacked laminated transparent materials of varying index of refraction formed in any combination, or a gradient index modified glass, perhaps assembled on the LED pitch spacing.

In the embodiments herein described, a power source may be constructed and arranged as seen in Fig. 17 wherein each line of LEDs in an array is powered from a separate programming source for sequencing or to vary the power to each line.

The power density output of the modules can be tested using a machine vision inspection technique, as seen in Figs. 18 and 19, where the individual intensity of each light module is measured. This is accomplished by placing a module 218 under an inspection camera 220 such as that shown and described in published U.S. Application US2002/0053589, filed October 2, 2001, incorporated herein by reference. The camera

aperture A (Fig. 19) is set so that light output of the module results in pixel gray scale values less than 255. The location and region of interest of each individual solid-state light emitter is defined and the intensity of each solid-state light emitter is measured. The output intensity of all of the solid-state light emitters are digitally imaged and algorithms are used to measure overall output performance of each module to identify any elements that are not working. Camera 220 measures light balancing, light distribution, and overall intensity of each module. As discussed above, power density used herein is in mW/cm2. Power density may be measured at the work surface or at the exit of the light source and is typically measured through optical elements. An average power meter 222 with an appropriately sensitive detector at the wavelength of the light source is set up with the camera aperture opening so that the light output from the source is larger in area than the diameter of the aperture. The total average power into meter 222 within the aperture opening is recorded on meter 222. The optical power density for any area of the LED array is then the ratio of the measured power on the meter in mW and area of detector in cm^2. The intensity of each light source in an array may be measured and the total illumination of the array is simultaneously measured so that the relative intensity of each light source relative to the overall intensity of the array is verified.

Persons skilled in the art will recognize that many modifications and variations are possible in the details, materials, and arrangements of the parts and actions which have been described and illustrated in order to explain the nature of this invention and that such modifications and variations do not depart from the spirit and scope of the teachings and claims contained therein.

Claims

1. A lighting module comprising:

a substrate thermally coupled to a heat sink and having drive circuitry to provide power to an array of solid-state light emitting devices surface disposed on the substrate, the module producing a light output power density of at least about 50 mW/cm^2.

2. The lighting module of claim 1, wherein the solid-state light emitting devices are LEDs, VCSELs, or laser diodes.

3. The lighting module of claim 1, wherein the substrate comprises a thermally transmissive material and supports the drive circuitry.

4. The lighting module of claim 3, wherein the substrate is made of one of ceramic, semiconductor, glass, or a dielectric with thermal vias.

5. The lighting module of claim 1, wherein the substrate includes a reflective coating for enhancing the light power output efficiency of the module.

6. The lighting module of claim 1, wherein each module includes at least 100 solid-state light emitting devices.

7. The lighting module of claim 1, wherein conversion efficiency of electrical energy to photoenergy is greater than 10%.

8. The lighting module of claim 1, wherein the heat sink is associated with cooling means.

9. The lighting module of claim 8, wherein the cooling means includes a temperature sensor for controlling the temperature of the heat sink.

10. The lighting module of claim 1, further comprising a controller for controlling the voltage, current, pulse width and/or profiling of the drive circuitry associated with one or more to the solid-state light emitting devices.

11. The lighting module of claim 1, further comprising at least one optical element coupled to the LEDs for optically transmitting light at the predetermined wavelength.

12. The lighting module of claim 11, wherein the at least one optical element performs spectral filtering of the light output.

13. The lighting module of claim 11, wherein the at least one optical element includes a lens micro array of optically reflective, transmissive, refractive, and/or diffractive optical elements that focus and/or optically multiply the intensity of the light output in one or more axes.

14. The lighting module of claim 1, wherein the module includes means for controlling the light output over a target surface.

15. The lighting module of claim 1 wherein the controlling means is capable of performing a light output averaging over a target material.

16. The lighting module of claim 11, wherein the at least one optical element is optically transmissive and has an optical coating to modify the light output in a predetermined manner.

17. The lighting module of claim 11, further including a transmissive gas sealingly disposed between the solid-state light emitting devices and the at least one optical element, wherein the gas is optically matched to the solid-state light emitting devices, the substrate, and/or the at least one optical element to minimize transmission losses.

18. The lighting module of claim 1, wherein the module is capable of outputting light in a wavelength less than about 425nm.

19. A system for inducing a predetermined material transformation in a predetermined target material, the system including the lighting module of claim 1, wherein the module is capable of a power output sufficient to cause the desired material transformation in the target material.

20. The lighting module of claim 19, wherein the wavelength output is less than about 400nm and the at least one optical element includes a reflective, refractive, or diffractive micro lens array that collimates the light output to less than about 5 degrees.

21. The system of claim 19, wherein the system is adapted to perform a photolithography operation.

22. The lighting module of claim 1, wherein the solid-state light emitters in the array are arranged in a center-to-center spacing of about 3mm or less.

23. The lighting module of claim 1, wherein the module is movably disposed on a support relative to a target material to improve the uniformity of the light output striking the target.

24. The lighting module of claim 23, wherein the light module is disposed relative to a target so that light output striking the target covers at least about 90% of the target area.

25. The lighting module of claim 1, wherein the drive circuitry includes passive components in series or parallel with the solid-state light emitting devices and which can be laser trimmed to improve the uniformity of light output of the array.

26. The lighting module of claim 1, wherein the solid-state light emitting devices output wavelengths representing red, green, and blue regions of the spectrum.

27. The lighting module of claim 26, wherein the drive circuitry allows emitters for each of a red, green, and blue color to be turned on separately and pulsed for durations less than 100msec.

28. A projection system including the lighting module of claim 26, wherein the output of one or more solid-state light emitting devices for each color wavelength is greater than 800 lumens.

29. A system for inducing secondary light emission including the lighting module of claim 1, wherein the module is capable of a light output at a wavelength of less than about 400nm, and wherein the module is capable of a power output density greater than about $10mW/cm^2$, and the module is adapted to induce a target molecule to fluoresce or phosphoresce in an inspection, measurement, or material analysis application.

30. The system of claim 29 wherein the system is adapted so that fluorescence or phosphorescence in a first target material is used to illuminate, sterilize, inspect, or measure characteristics of a second target material.

31. A sterilization system including the lighting module of claim 1, wherein the module is capable of a light output in spectral region that causes death or loss of reproductive capabilities of undesirable microorganisms that may be disposed on a target material.

32. A semiconductor materials inspection system including the lighting module of claim 1, wherein the solid-state light emitting devices are capable of emitting light in the infrared region between about 1050 nm and about 2.5 um.

33. The lighting module of claim 1, wherein the drive circuitry includes a programmable current source to control the solid-state light emitting devices to sequence, balance, or otherwise modulate power to the module.

34. A lighting module comprising:

a substrate having drive circuitry to provide power to an array of LEDs disposed on the substrate, the LEDs being arranged in a center-to-center spacing of about 3mm or less.

35. The lighting module of claim 34 wherein a heat sink is thermally coupled to the substrate.

36. The lighting module of claim 35 wherein the lighting module is capable of a power output of at least about 50 mW/cm^2.

37. The lighting module of claim 36 further comprising a housing in which the module is enclosed, the housing including a window for transmission of light emitted from the LEDs.

38. The lighting module of claim 37, wherein the module further includes a controller for controlling the voltage, current, pulse width and/or profiling of a drive circuitry associated with one or more LEDs in the array.

39. The lighting module of claim 38, further including a temperature controlling means associated with the module.

40. The lighting module of claim 39 wherein the temperature controlling means includes a temperature sensor.

41. The lighting module of claim 1 or 34, wherein the drive circuitry allows one or more emitters to be turned on separately and pulsed for durations less than 100msec.

42. A method of radiating a target object comprising:

providing a substrate thermally coupled to a heat sink and having drive circuitry to provide power to an array of solid-state light emitting devices surface disposed on the substrate, the module producing a light output power density of at least about 50 mW/cm^2; and

activating the module so that radiation emitted from the module is transmitted to a surface of the target object.

43. A method of radiating a target object comprising::

providing a substrate having drive circuitry to provide power to an array of LEDs disposed on the substrate, the LEDs being arranged in a center-to-center spacing of about 3mm or less; and

activating the module so that radiation emitted from the module is transmitted to a surface of the target object.

44.The method of claim 42 or 43, wherein the emitted light is of a predetermined wavelength that induces a material transformation in a predetermined target object.

45.The method of claim 42 or 43 wherein the target object is a semiconductor object, liquid crystal array, stencil, hybrid circuit, electronic component, or circuit board.

46. The method of claim 42 or 43, wherein the emitted light is of a selected wavelength for sterilizing a surface of the target object, and the light is emitted for a time sufficient to achieve a desired degree of sterilization.

47. The method of claim 46 wherein the target object being sterilized is a foodstuff, air or gas, water, or a biological material, or the implements for handling or performing functions on a biological material, and the material transformation causes the death or loss of reproductive capabilities of undesirable microorganisms that may be disposed on the target object.

48. The method of claim 42 or 43, wherein the material transformation is an ionization reaction.

49. The method of claim 42 or 43, wherein the material transformation results in photo- ablation of the target object.

50. The method of claim 42 or 43, wherein the material transformation results in the initiation, termination, acceleration, or deceleration of a predetermined chemical or biological process.

51. The lighting module of claim 42 or 43, wherein the molecular transformation is photochemical disassociation or degradation of molecules in the target object.

52. The method of claim 42 or 43 wherein the emitted light is used to inspect a target object and the emitted light is of a wavelength sufficient to perform a desired inspection.

53. The method of claim 52 wherein the method is performed in the fabrication or inspection of a semiconductor based device or other electronic component.

54. A method of performing an operation requiring a light power output density of greater than 50 mW/cm^2, comprising the steps of;

providing a substrate mounted on a heat sink and having an electrically conductive drive circuitry to provide power to an array of solid-state light emitting devices disposed on the substrate in a dense configuration producing a light output of a uniform primary wavelength.

55. A method of performing a test on a solid-state light emitting module that includes a substrate mounted on a heat sink and having an electrically conductive drive circuitry to provide power to an array of unpackaged solid-state light emitting devices surface mounted on the substrate in a dense configuration producing a light output of a primary wavelength to perform an operation requiring a power output density greater than 50 mW/cm^{2,} comprising the steps of;

utilizing a machine vision technique to measure intensity of light output of each solid-state light emitting device and the uniformity of light output of the entire module.

56. A method of manufacturing a lighting module comprising:

providing a substrate and thermally coupling the substrate to a heat sink, the substrate having drive circuitry to provide power to an array of solid-state light emitting devices surface and;

disposing on the substrate the array of light emitting devices, the array of light emitting devices producing a light output power density of at least about 50 mW/cm^2.

57. A method of manufacturing a lighting module comprising:

providing a substrate having drive circuitry to provide power to an array of LEDs; and

disposing an array of LEDs on the substrate, the LEDs being arranged in a center-to-center spacing of about 3mm or less.

58. A system for producing light output to perform a variety of application processes comprising:

a substrate thermally coupled to a heat sink and having drive circuitry to provide power to an array of solid-state light emitting devices surface disposed on the substrate, the module producing a light output power density of at least about 50 mW/cm^2.

59. A system for producing light output to perform a variety of application processes comprising:

a substrate having drive circuitry to provide power to an array of LEDs disposed on the substrate, the LEDs being arranged in a center-to-center spacing of about 3mm or less.

60. A device for producing light output to perform a material transformation process on a target material comprising:

a substrate thermally coupled to a heat sink and having drive circuitry to provide power to an array of solid-state light emitting devices surface disposed on the substrate along an axis, the module producing a light output power density of at least about 50 mW/cm^2.

61. A device for producing light output to perform a material transformation process on a target material comprising:

a substrate having drive circuitry to provide power to an array of LEDs disposed on the substrate, the LEDs being arranged in a center-to-center spacing of about 3mm or less.

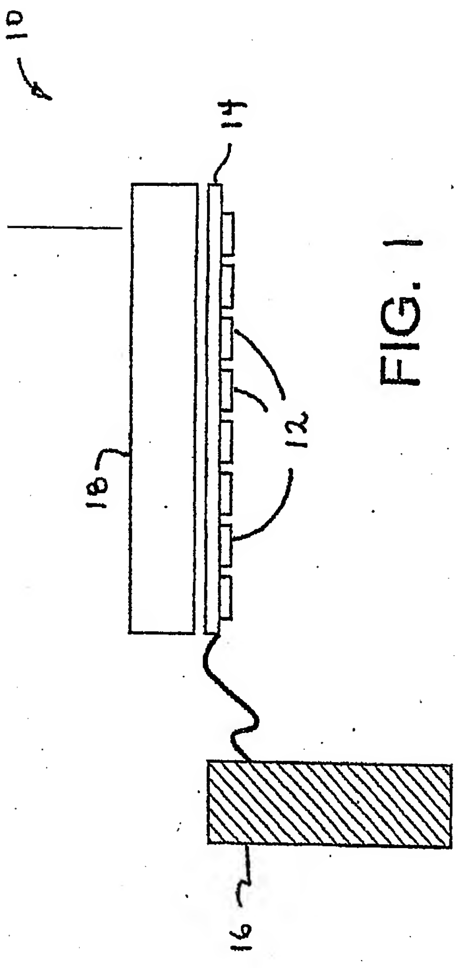


FIG. 1

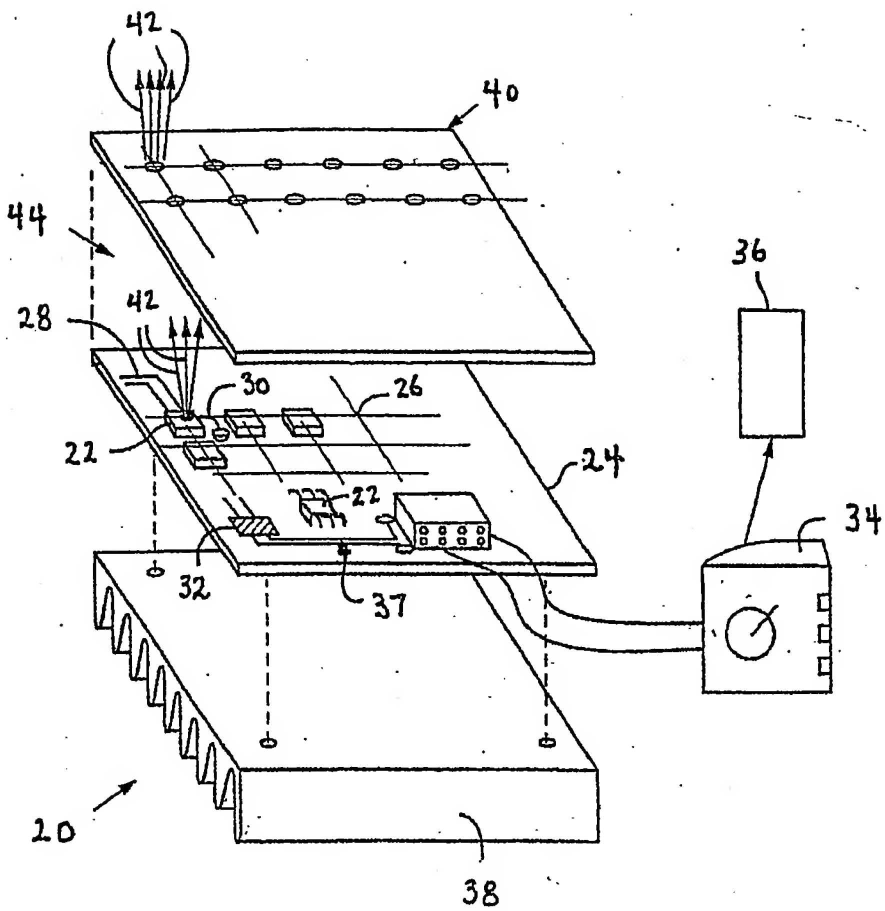
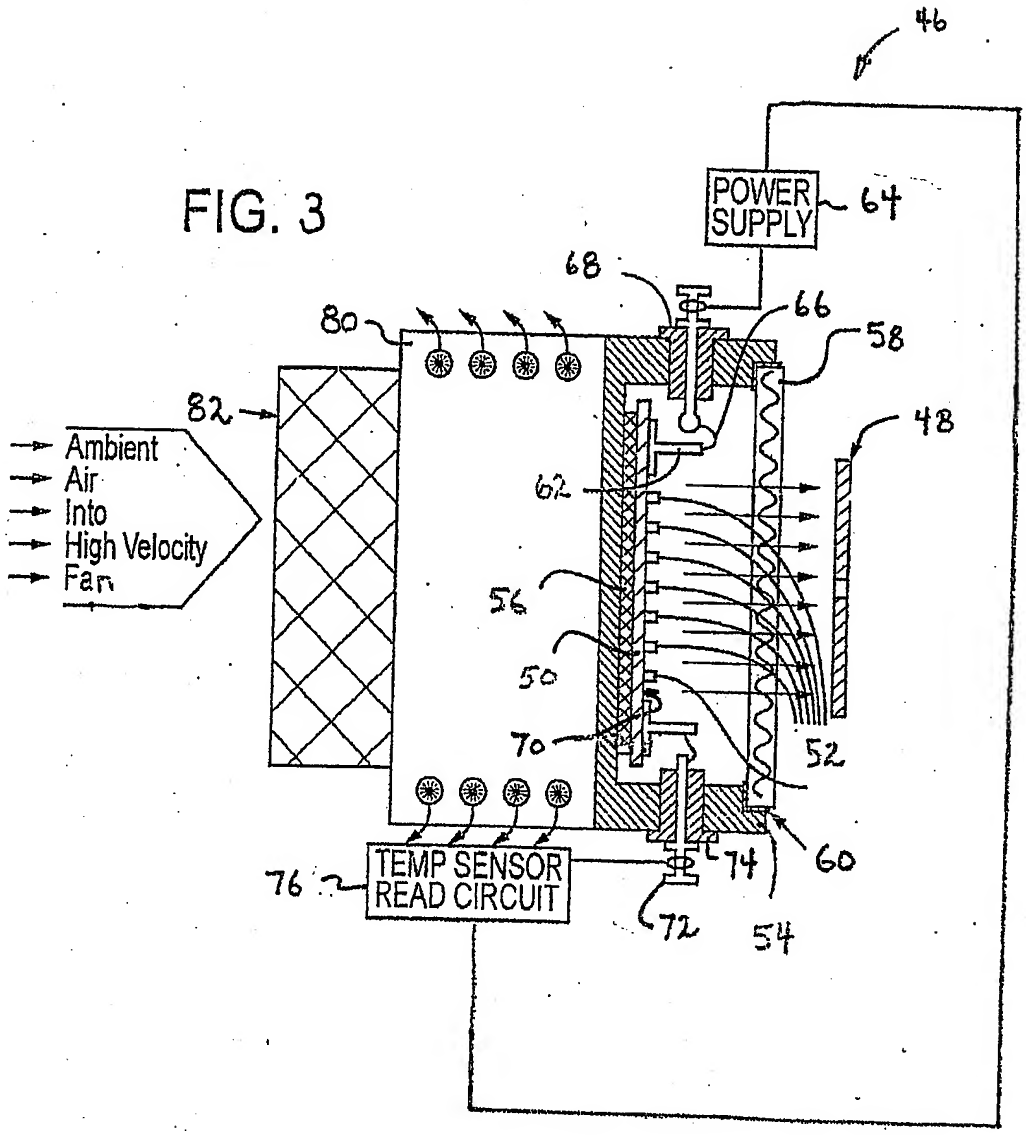


FIG. 2

FIG. 3


46
POWER SUPPLY
64
68
66
58
80
82
48
Ambient
Air
Into
High Velocity
Fan
62
56
50
70
52
60
74
54
72
76
TEMP SENSOR
READ CIRCUIT

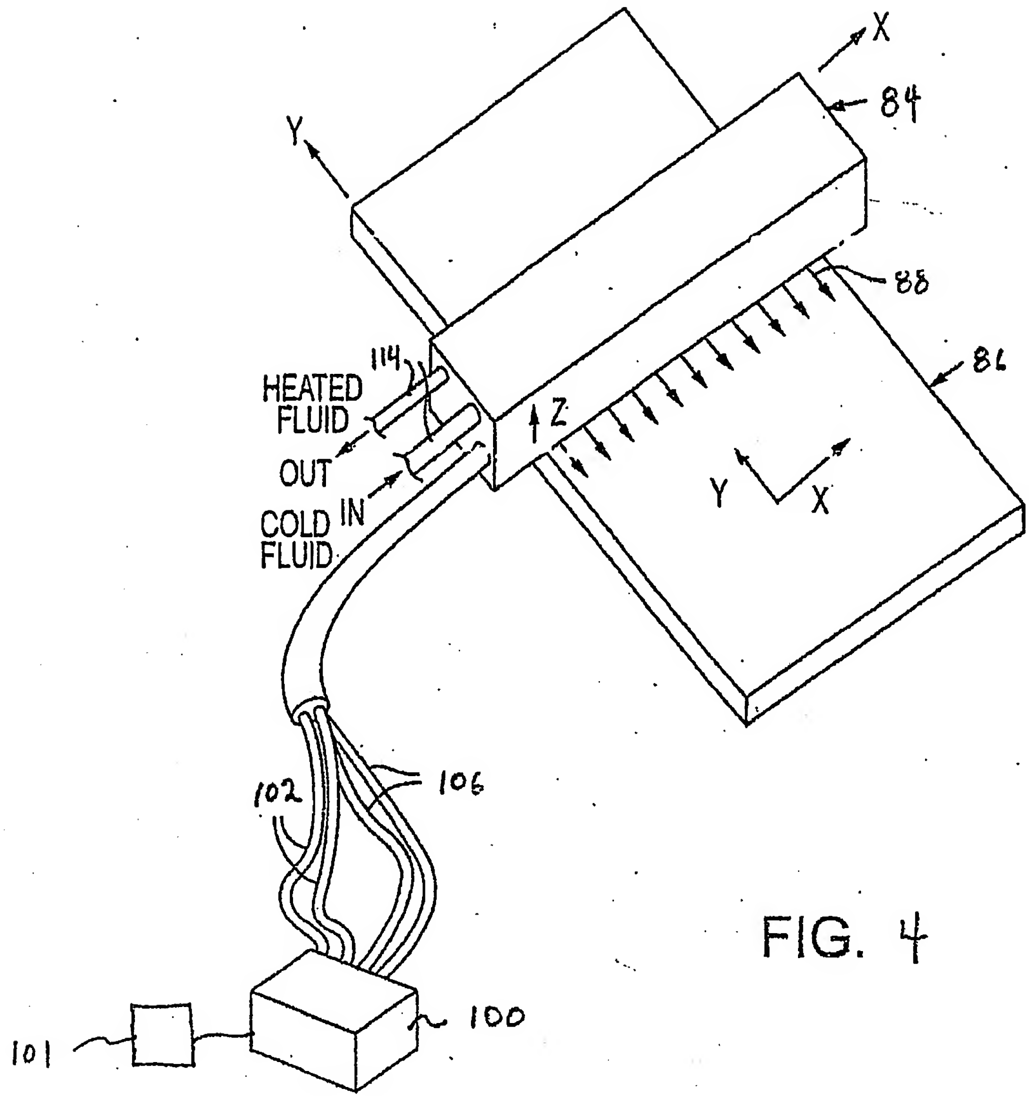

X
84
Y
88
86
114
HEATED
FLUID
OUT
IN
COLD
FLUID
Z
Y
X
102
106
100
101

FIG. 4

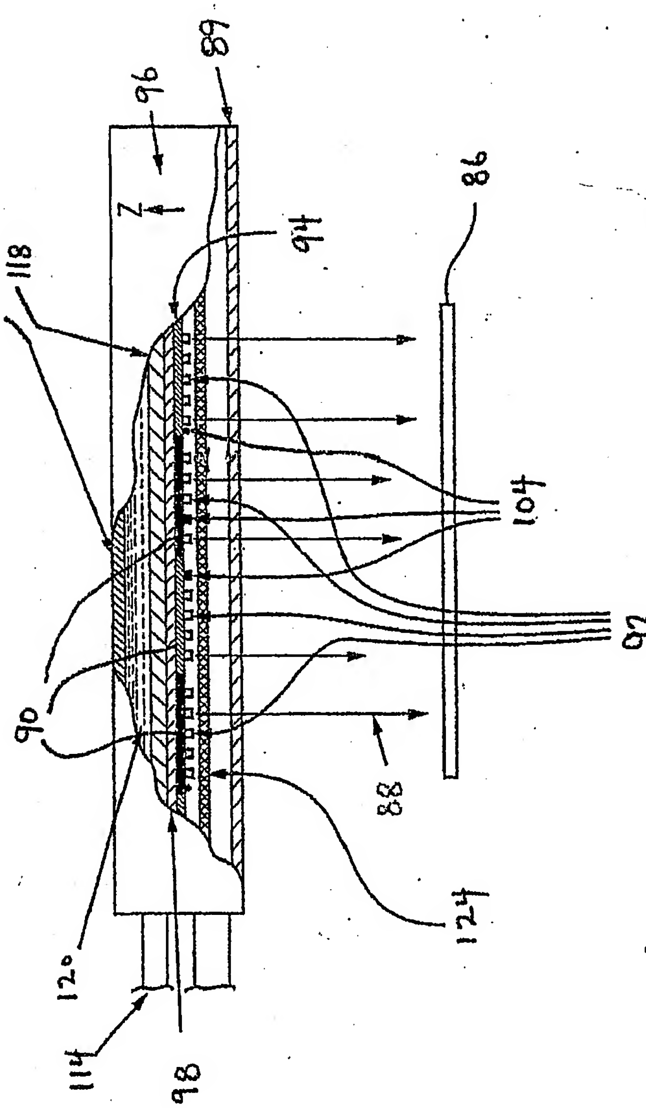


FIG. 5

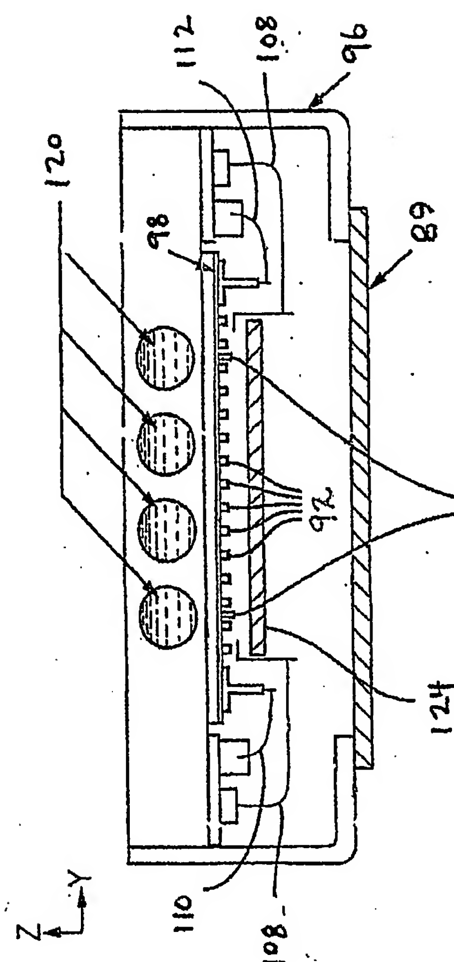


FIG. 6

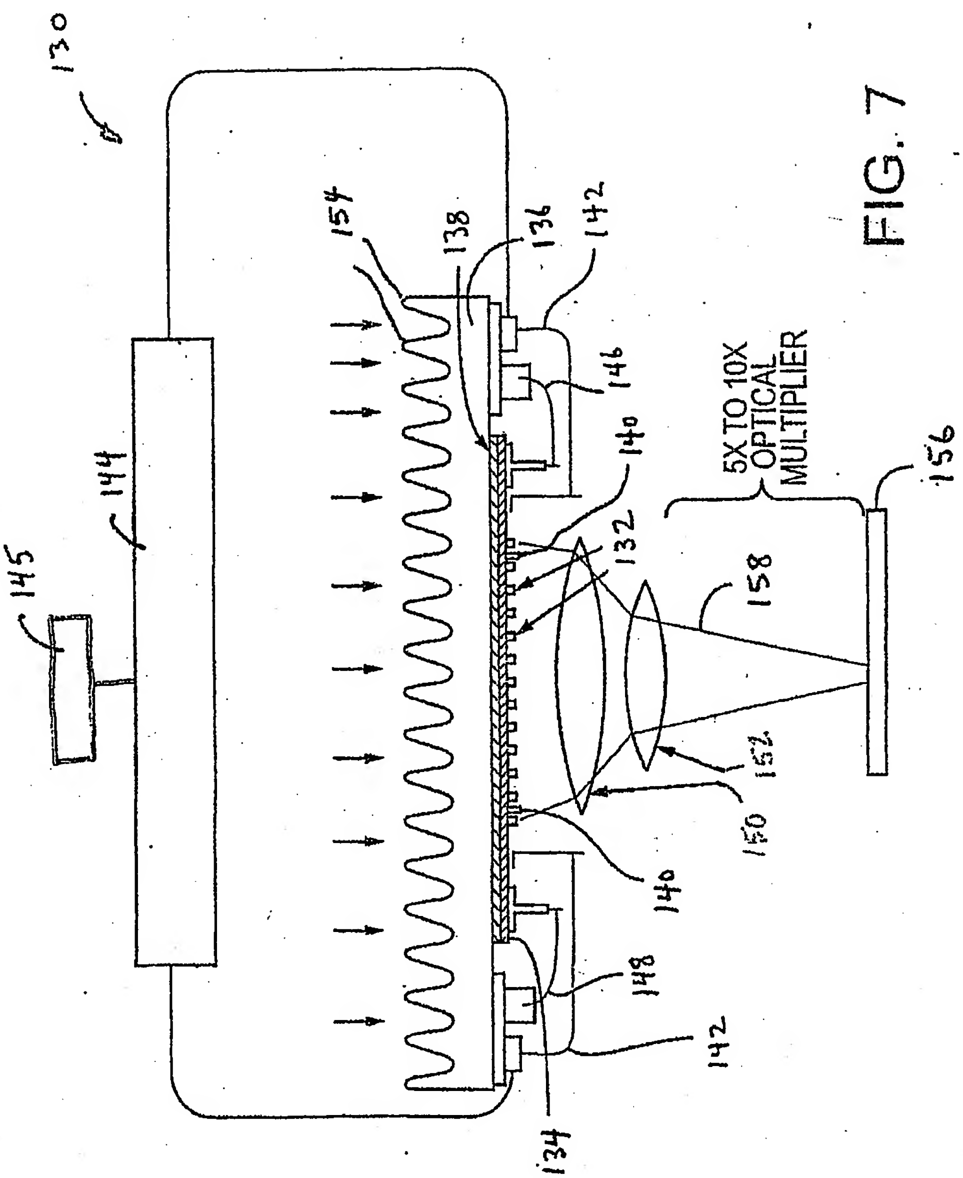
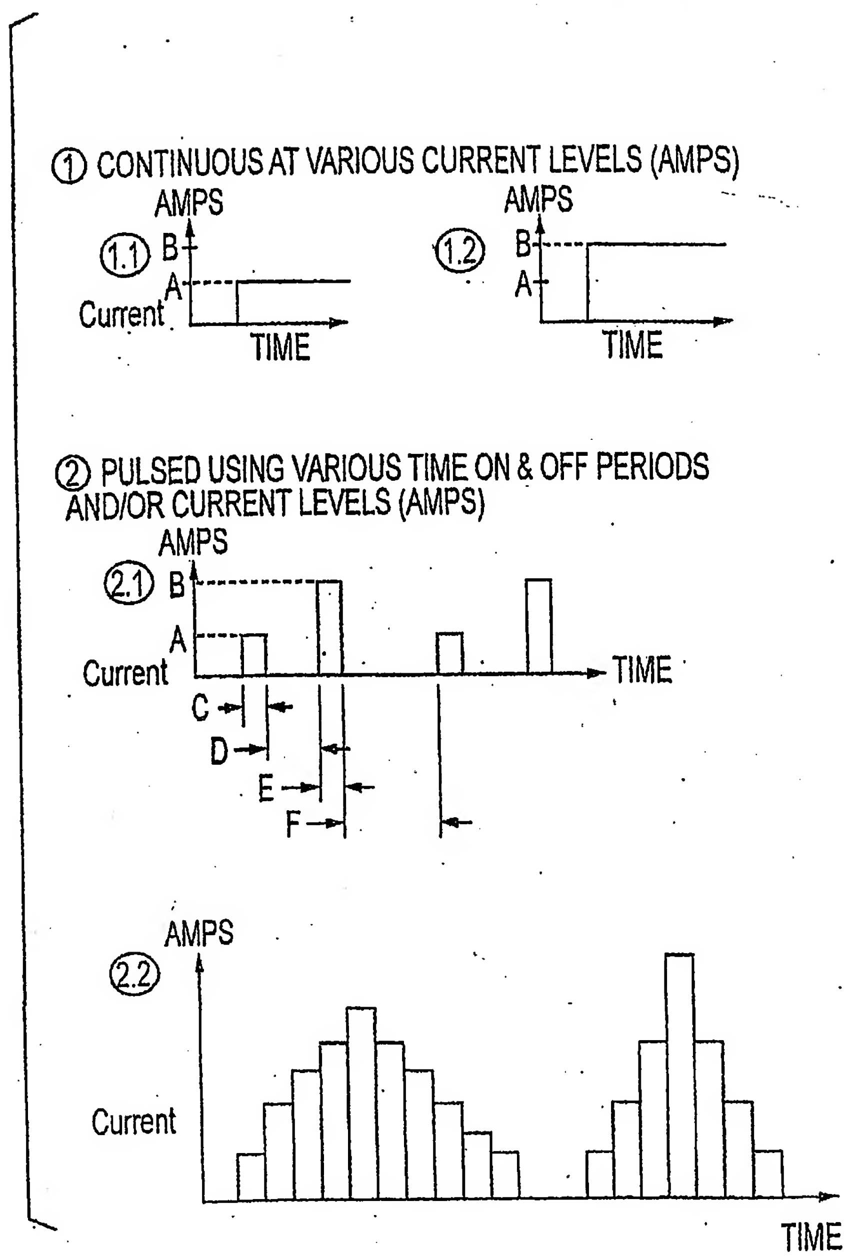

130
145
144
154
138
136
142
146
140
132
158
5X TO 10X
OPTICAL
MULTIPLIER
156
152
150
140
148
142
134

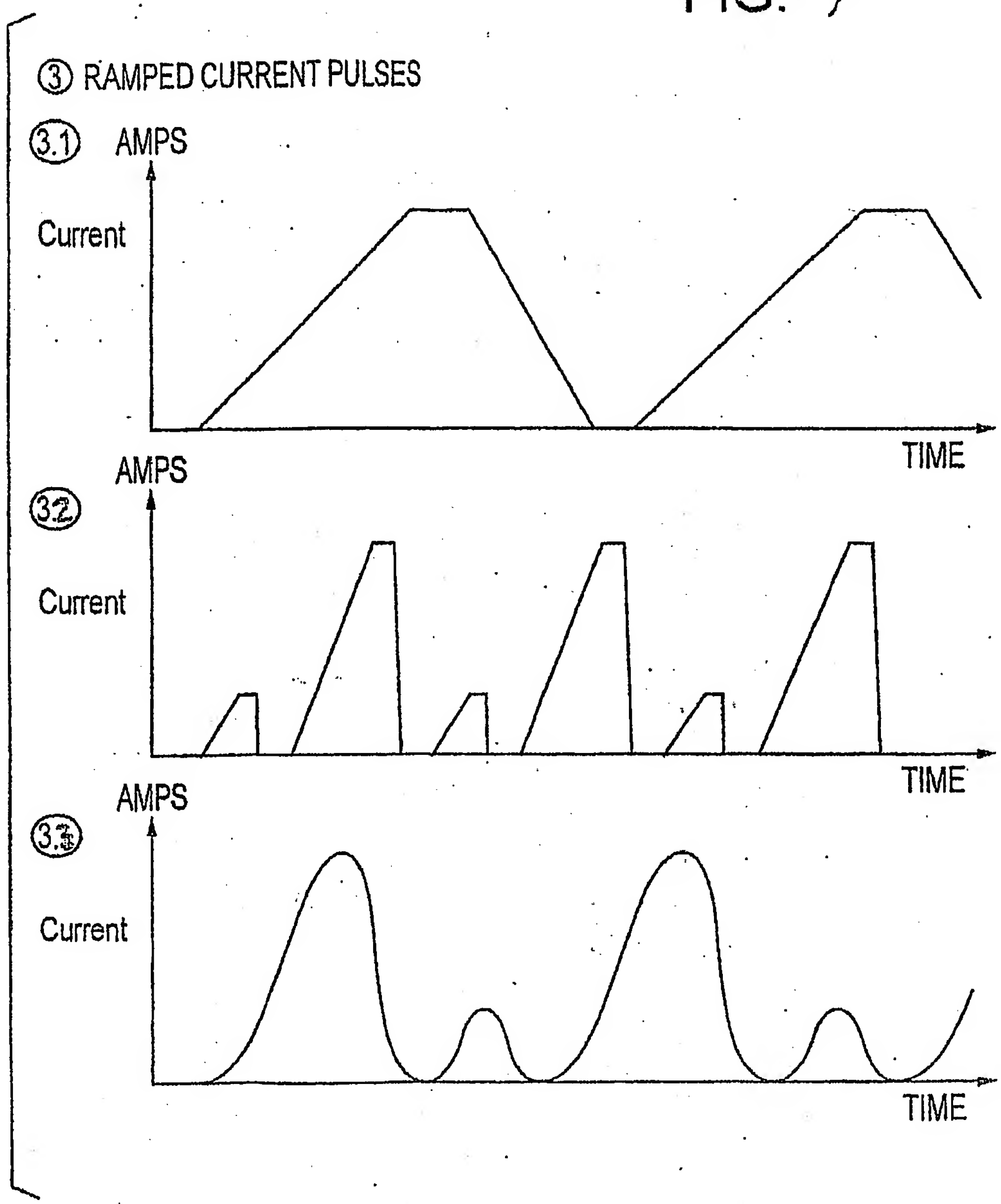
FIG. 7

FIG. 8



① CONTINUOUS AT VARIOUS CURRENT LEVELS (AMPS)
1.1
AMPS
B
A
Current
TIME
1.2
AMPS
B
A
TIME
② PULSED USING VARIOUS TIME ON & OFF PERIODS AND/OR CURRENT LEVELS (AMPS)
2.1
AMPS
B
A
Current
TIME
C
D
E
F
2.2
AMPS
Current
TIME

FIG. 9


③ RAMPED CURRENT PULSES
3.1
AMPS
Current
TIME
3.2
AMPS
Current
TIME
3.3
AMPS
Current
TIME

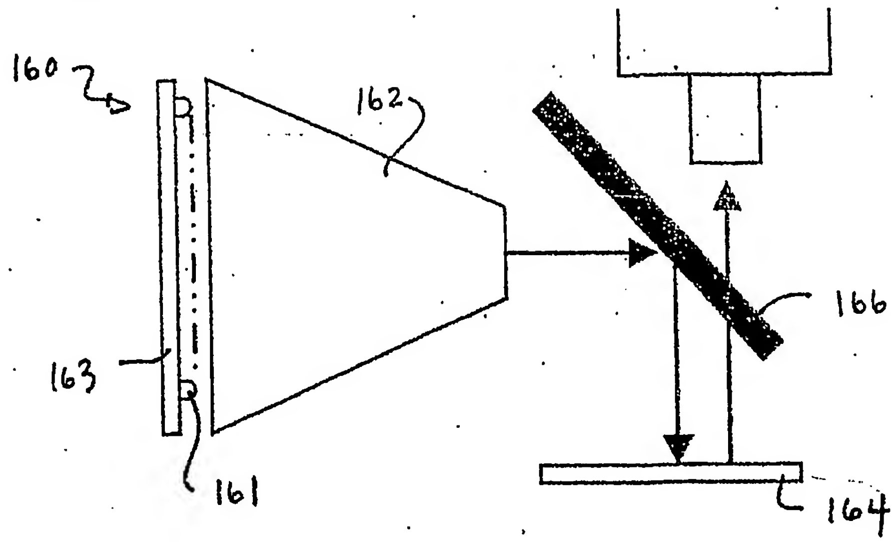


FIG. 10

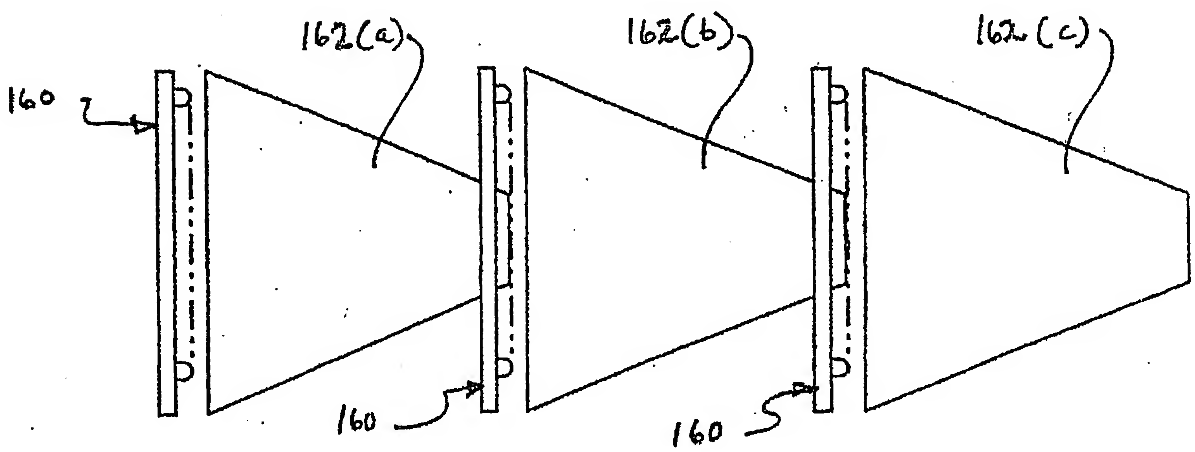


FIG. 11

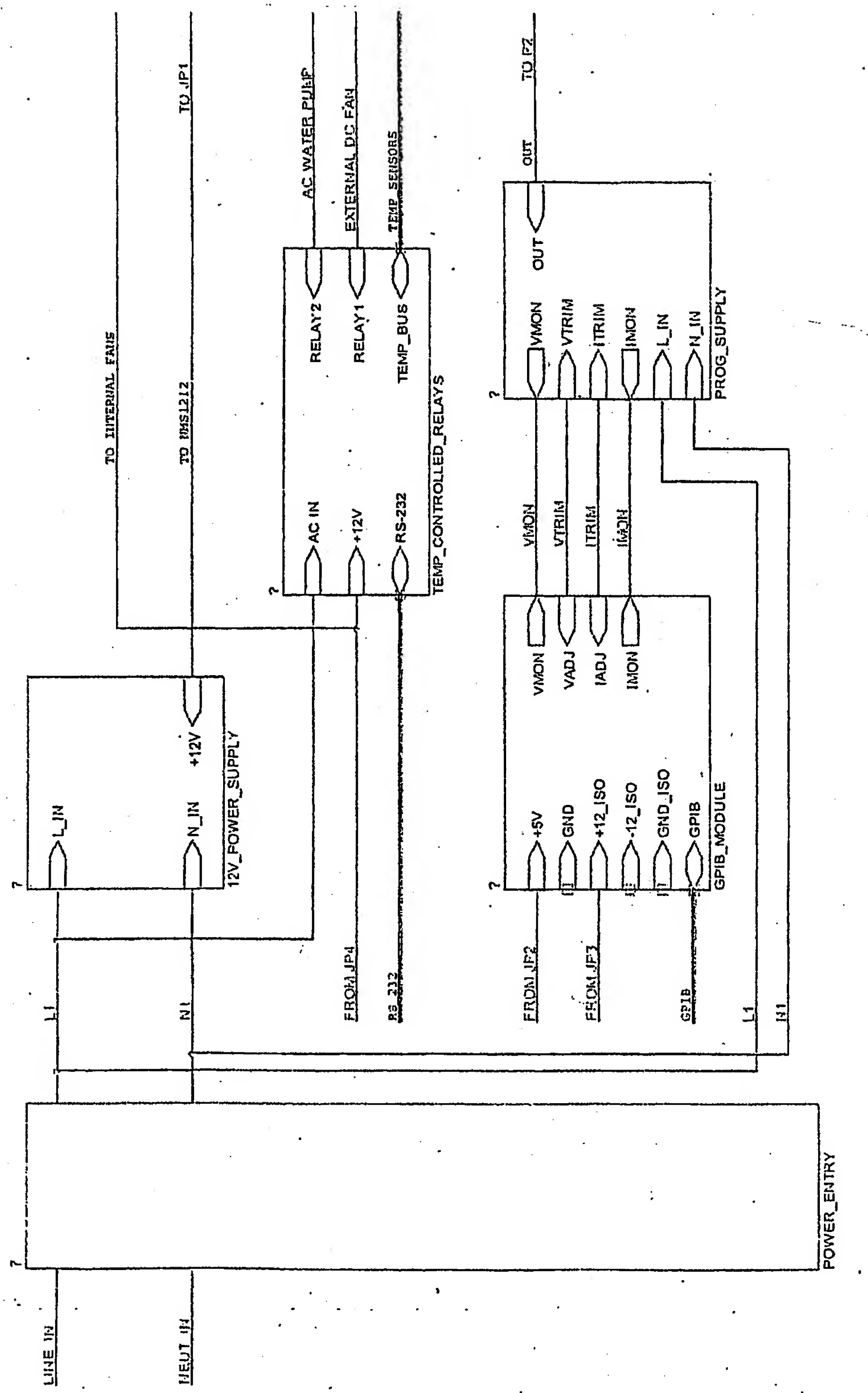

TO INTERNAL FANS
TO JP1
TO HMS1212
AC WATER PUMP
EXTERNAL DC FAN
TEMP SENSORS
RELAY2
RELAY1
TEMP_BUS
AC IN
+12V
RS-232
TEMP_CONTROLLED_RELAYS
OUT
TO P2
VMON
VTRIM
ITRIM
IMON
L_IN
N_IN
PROG_SUPPLY
VADJ
IADJ
+5V
GND
+12_ISO
-12_ISO
GND_ISO
GPIB
GPIB_MODULE
L_IN
N_IN
+12V
12V_POWER_SUPPLY
FROM JP4
RS 232
FROM JP2
FROM JP3
L1
N1
POWER_ENTRY
LINE IN
NEUT IN

FIG. 12

FIG. 13a

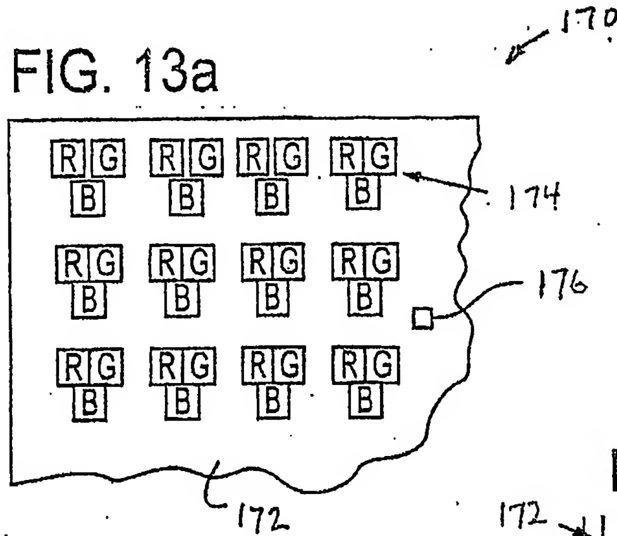
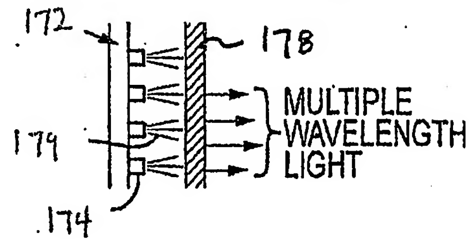


FIG. 13b



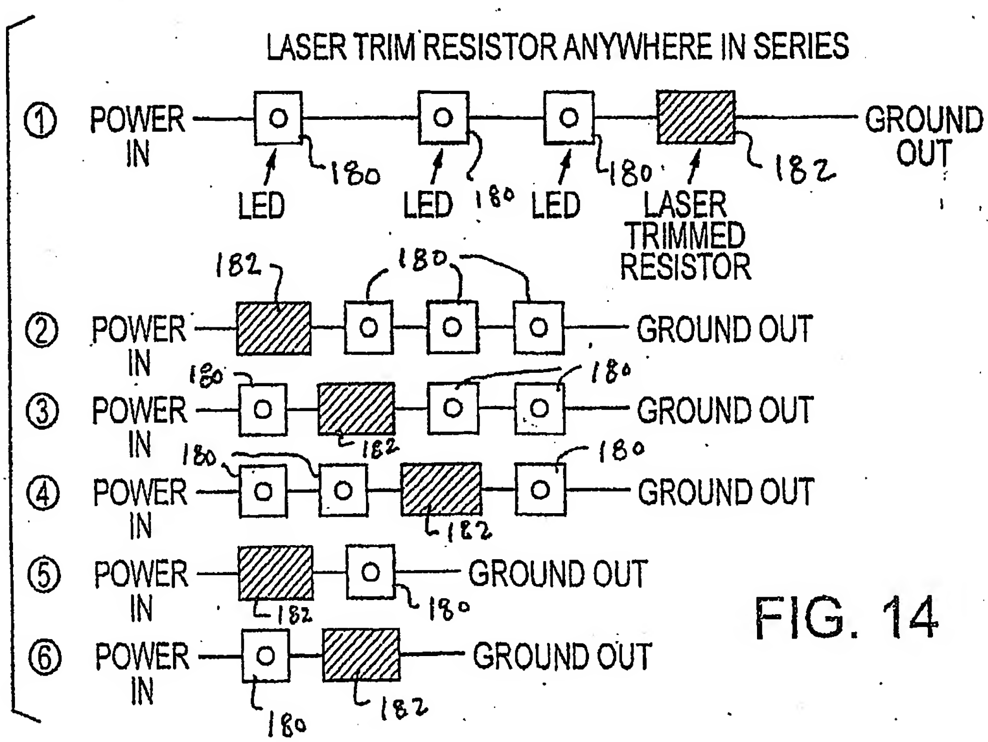


FIG. 14

FIG. 15

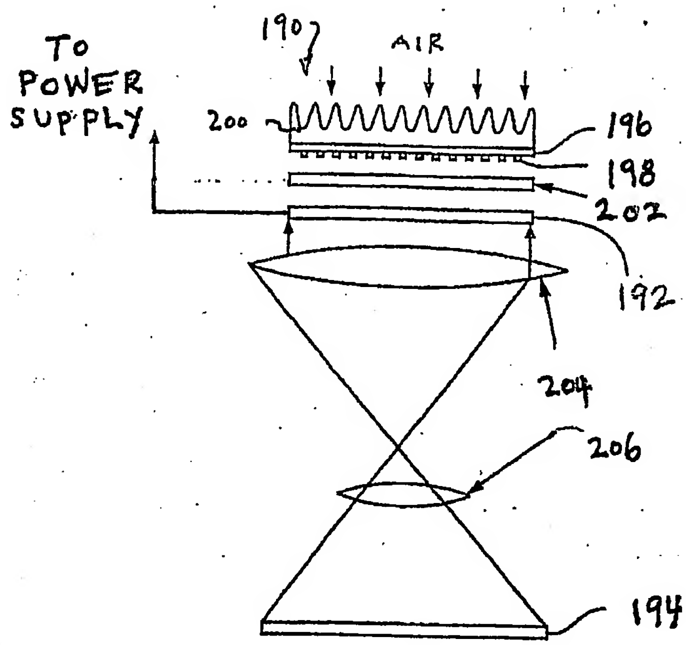
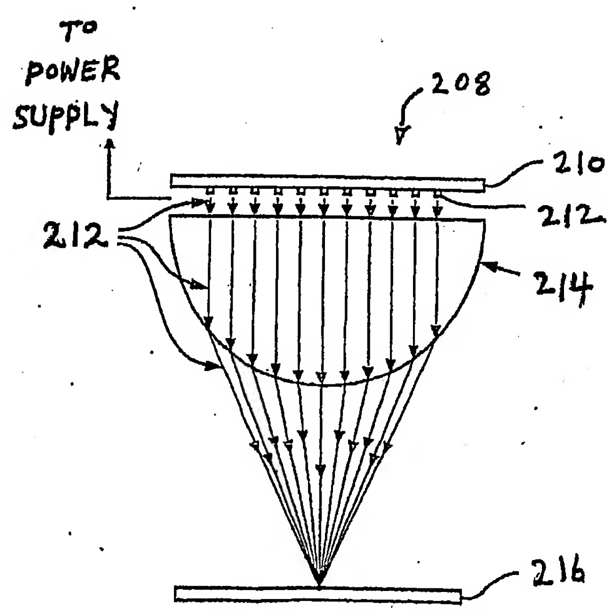

TO POWER SUPPLY
190
AIR
200
196
198
202
192
204
206
194

FIG. 16


TO POWER SUPPLY
208
210
212
212
214
216

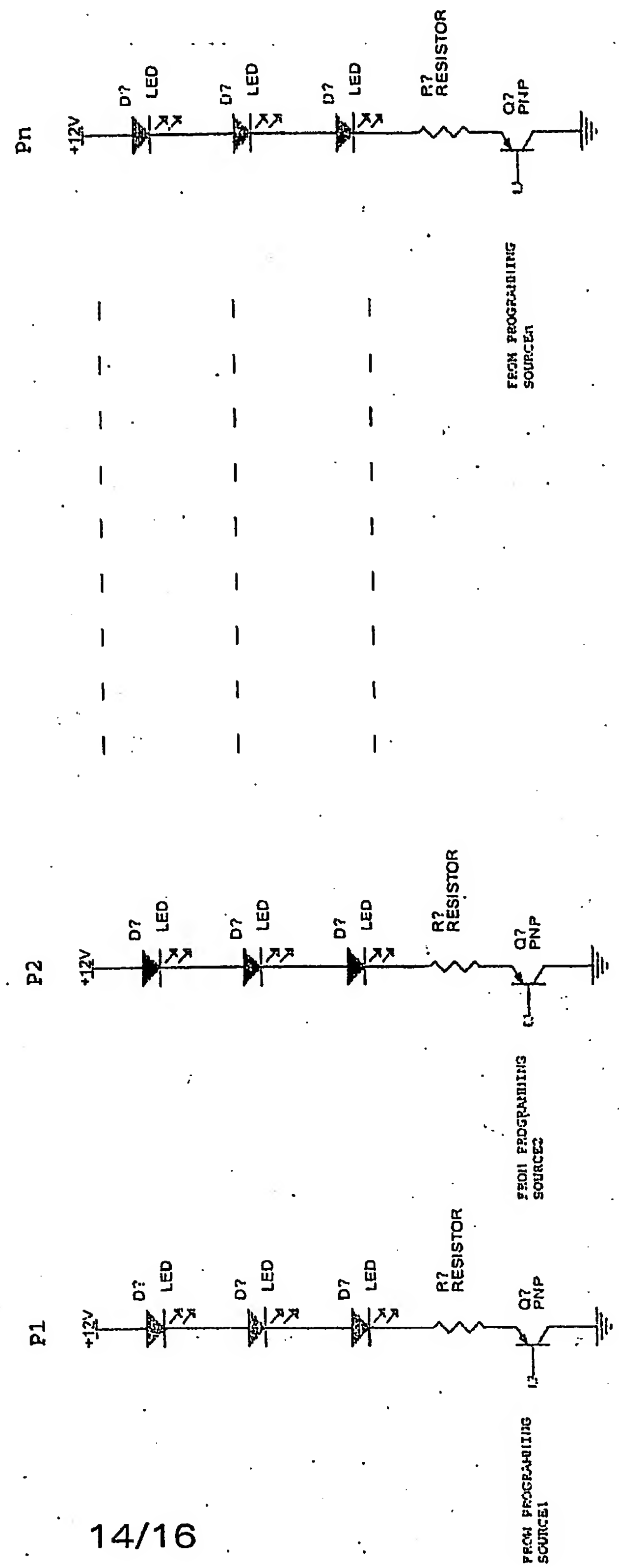


FIG. 17

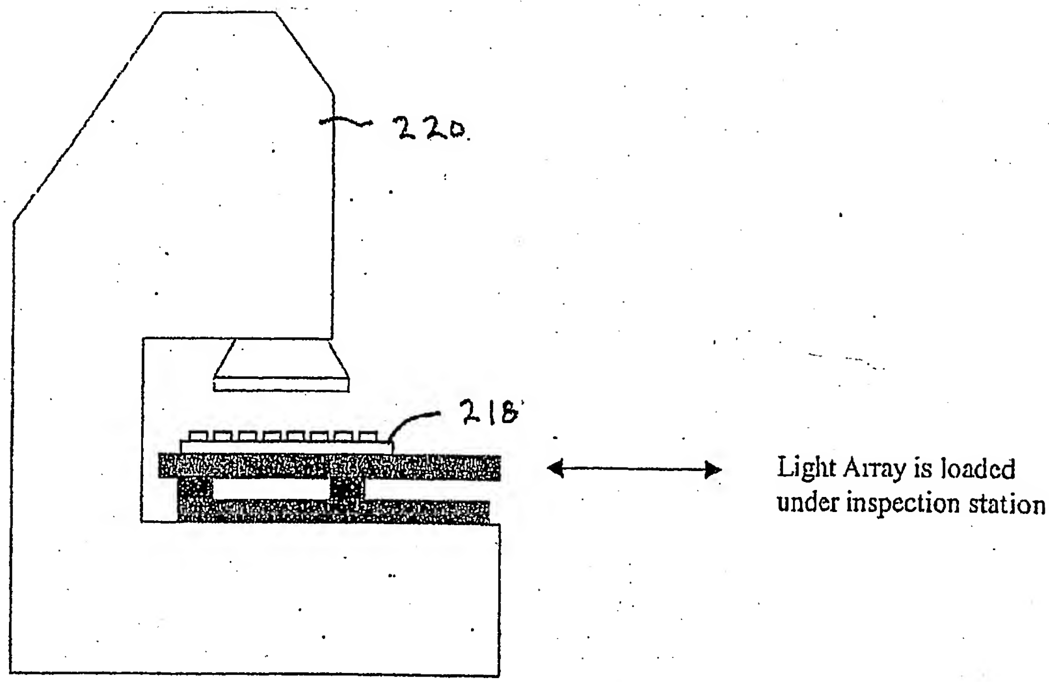


FIG. 18

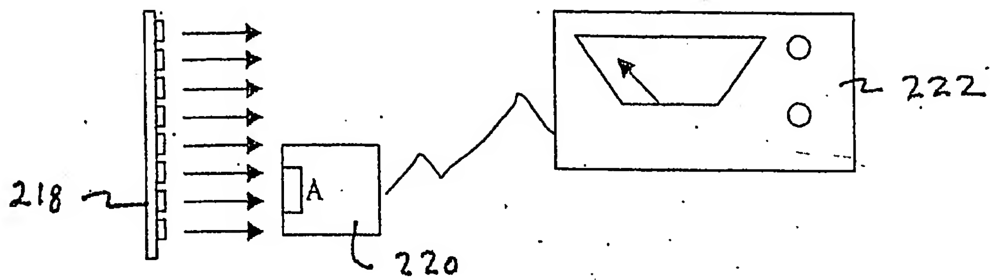


FIG. 19